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Summary
Performance in detecting a 50 ms pure-tone signal in a longer tone-burst masker was evaluated as a function of the delay between masker and signal onset. Delays from 500 ms to 5 s were used, and detection was measured in terms of sensitivity d'. Performance was also measured for a continuous masker. In a first experiment, the masker and the signal had the same frequency (500, 1000, 2000, 4000 and 8000 Hz). In this case, sensitivity increased with delay for high frequencies and for high masker levels. In a second experiment, the masker and the signal had different frequencies; the masker was set at 4 kHz and the signal frequency was inside and outside the critical band of the masker. For this second case, the results depended on masker level and signal frequency: increasing the delay for a 50 dB SL masker did not improve detection; at 80 dB SPL, however, delaying the signal improved detection for signal frequencies close to the masker frequency. The assumption is made that the improved detection for long durations of the masker originates from a long-term decrease in the firing rate of the auditory nerve fibers.

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1. Introduction

Studies on auditory detection and simultaneous masking have a long history [1, 2, 3, 4]. Most investigators used maskers of 200 to 800 ms; much less attention has been given to longer maskers. In the 1960's, research was done on the detection of a short, narrow-band signal masked by a longer wide-band sound. It was shown that the signal threshold increases when the signal is presented in the first few milliseconds of the masker relative to when it is presented after some hundreds of milliseconds (200 to 800 ms). This increase, the overshoot effect, is large when a short high-frequency pure tone (less than 10 ms) is masked by a broad-band noise, and also when a narrow-band noise is masked by a broad-band noise [5, 6, 7]. The term "overshoot" was used for broad-band maskers and narrow-band signals with center frequencies above 2 kHz.

Masked signal detection was also studied for narrow-band signals and maskers, and for pure tones [8, 9, 10, 11]. The authors found that the masker "fringe" (that is, an extension of masker duration before signal onset) had an effect on signal detection. Rather than overshoot they used the terms "auditory enhancement" [12], "adaptation of masking" [13] or "temporal decline of masking" [14]. If both masker and signal were pure tones, a decrease in signal threshold with increasing signal onset delay was observed when the masker frequency was higher than the signal frequency [8, 15, 16, 10, 11].

It has always been assumed that detection would stay constant for delays longer than 500 ms. McFadden [17] noted that nobody had ever proved that, and Canévet *et al.* [18] showed that detection threshold sometimes varied for durations of 1 to 30 s. Canévet *et al.* compared the detection of an intensity increment in two conditions: In the continuous condition, the masker was on continuously, with a short increment every 5 s; in the pulsed condition, the masker was on for 2 s with the increment 1 s after its onset. Increment detection was better when the masker was continuous than when it was pulsed. Scharf *et al.* [19] showed that this result depended on signal frequency: detection did not improve at 500 Hz, although a large effect was found at 4 kHz.

Originally, Canévet *et al.* [18] and Scharf *et al.* [19] sought to compare detection and loudness adaptation. Canévet *et al.* asked whether loudness adaptation to a sustained sound would affect the detection of an intensity increment of that sound. Intuitively, we would expect a decrease in masker loudness to improve detection of an intensity increment. But Florentine *et al.* [20] showed that intensity discrimination for low sound levels was worse than for high levels. One would, therefore, expect the detection of an intensity increment to be degraded by adaptation to the masker. The third logical possibility was that adaptation would have no effect on intensity discrimination; that is, there would be an adaptation to both the signal and the masker.

In fact, Canévet *et al.* [18] showed that detection of an intensity increment in a sound is improved after a long exposure to this sound, but this improvement was not correlated with loudness adaptation. Scharf *et al.* [19] suggested that peripheral neural adaptation [21, 22, 23, 24, 25] would explain this phenomenon.

In this paper we try to characterize and explain the improved detection of a signal after long exposure to a masker observed by Canévet *et al.* [18]. The Scharf *et al.* [19] experiment showed that this improvement occurs at 4 kHz and not at 500 Hz. In a first experiment, therefore, signal detection experiments were conducted for 0.5, 1, 2, 4 and 8 kHz masker frequencies with signal and masker at the same frequency. Since peripheral neural adaptation was commonly found for high-level stimuli, experiments were run at different masker levels (10 and 50 dB SL and 80 dB SPL) to determine whether level is an important parameter and to compare the psychoacoustical results with physiological data.

In a second experiment, the signal and masker differed in frequency. Green [8], Fastl [9], and Bacon and Viemeister [10, 11] reported a large decrease in pure-tone signal threshold when the fringe of a pure-tone masker with a different frequency was increased to 800 ms. In contrast, the decrease was small for pure tone signals and maskers of the same frequency. We wanted to test whether this result applied for longer delays. We ran experiments with 4 kHz, 50 dB SL and 80 dB SPL maskers, because these conditions most clearly showed improved detection with increasing onset delays in the first experiment. The signal frequency was set at 3720 Hz (just within the masker critical band), 2800 Hz (outside the masker critical band), and 3900 Hz (well within the masker critical band).

2. Method

2.1. Apparatus

The experiments were run in a sound-treated room. The pure tones were produced by an ADRET oscillator. WILSONICS programmable electronic switches with a $\cos^2$ shape were used to gate the signals, which were gated on and off at zero crossings. The level was set by WILSONICS programmable attenuators. The stimuli were presented via AKG K340 headphones. The experiment was controlled by a PDP 11/73 computer.

2.2. Procedure

Maskers and signals were presented to the right ear of the subject. First, the absolute threshold for the frequencies was measured by a two-interval forced-choice adaptive procedure [26] with a 2 down – 1 up rule. Signal duration was 300 ms; feedback was given after each trial.

Two conditions were tested. In the "continuous condition," the masker was on for the whole run, and in the "pulsed condition" the masker had a limited duration and was presented at regular intervals. For all conditions, signal duration was 50 ms, the rise and fall times were 50 ms for the masker, and 10 ms for the signal.

First, masked thresholds were measured in the continuous condition. The observation interval was presented 5 s after the masker onset, and every 5 s thereafter. This observation interval was indicated by a 500 ms spot on the subject's terminal, the signal (when it was presented) being temporally centered within the 500 ms interval. A Yes/No procedure was used with a 5 down – 1 up rule. The signal occurred randomly in 50% of the observation intervals. Signal and masker were added in phase. At the beginning of a run, the signal level was set 5 dB higher than the expected threshold.

Once the threshold had been determined with a continuous masker, the signal level was fixed at this threshold and d' was measured in the continuous and pulsed condition. To measure d' in the continuous condition, the signal sequence was identical to those used to measure masked threshold in this condition, except that signal level and experiment duration were fixed (about 5 min).

In the pulsed condition, the sequence was similar to that of the continuous condition, but the signal was presented Δt s after the masker onset, and the masker was turned off 1 s after the end of the signal. The value of Δt was chosen at random before each run and kept constant during the run. A pause was inserted between two presentations. It lasted from 2.5 to 3.5 s, depending on the delay, because the entire duration of a run was set to about 5 min whatever the Δt.

For both conditions (continuous and pulsed), sixty-four observation intervals were presented during a run, only the last sixty were taken into consideration. A d' value was computed after two runs (except in the pulsed condition, for $\Delta t = 5$ s: four runs and for $\Delta t = 12$ s: eight runs, to keep each run at the same duration), which means that d' was calculated over 120 presentations. The probability of signal occurrence was 0.5.

Since increment level was set to the threshold value obtained with a 5 down – 1 up Yes/No procedure with a continuous masker, the adaptative threshold should correspond to a d' value of 2.26. Of course this is only a statistical assumption. As we shall see in the next section, d' is sometimes different from 2.26 because the exact level of the increment needed to reach this value is difficult to evaluate. A d' greater than 3 was sometimes observed, but it never corresponded to a probability correct, p(c) of 1. When a p(c) of 1 was obtained for the first 60 presentations, the run was rejected, and the signal level was decreased. A new run was started with this reduced level.

2.3. Signals

In the first experiment, the signal and the masker were pure tones of the same frequency, namely: 0.5, 1, 2, 4 and 8 kHz. The levels of the masker were 10, 50 dB SL, and 80 dB SPL, but at 8 kHz we tested only the low levels (8 and 50 dB SL). The signal and masker were added in phase. In the second experiment, the signal and the masker were pure tones of different frequencies; the masker frequency was 4 kHz, and signal frequencies were 3.72 and 2.8 kHz, thus the signal was within and outside the critical band of the masker. The experiment was run on two subjects for another signal frequency: 3.9 kHz. In this experiment the masker levels were 50 dB SL and 80 dB SPL.

Δt was set at 0.5, 1.5, 2.5 and 5 s. At the beginning of the study, a 12 s delay was also tested (at 500 Hz for 10 and 50 dB SL and at 4 kHz for 50 dB SL). Since the subjects told us that their attention seemed to decrease with such a long duration, it was abandoned for the rest of the experiment. For the last runs (at 1 kHz and when the signal was at 3.9 kHz with a 4 kHz-80 dB SPL masker for subject S.P.), we did not run the 2.5 s delay, in order to make the experiment shorter.

2.4. Subjects

Eight subjects (6 males, 2 females, including the authors) participated in the experiments. All audiograms were within 10 dB of normal at all frequencies tested. Because of their lack of availability, different subjects had to be used for the

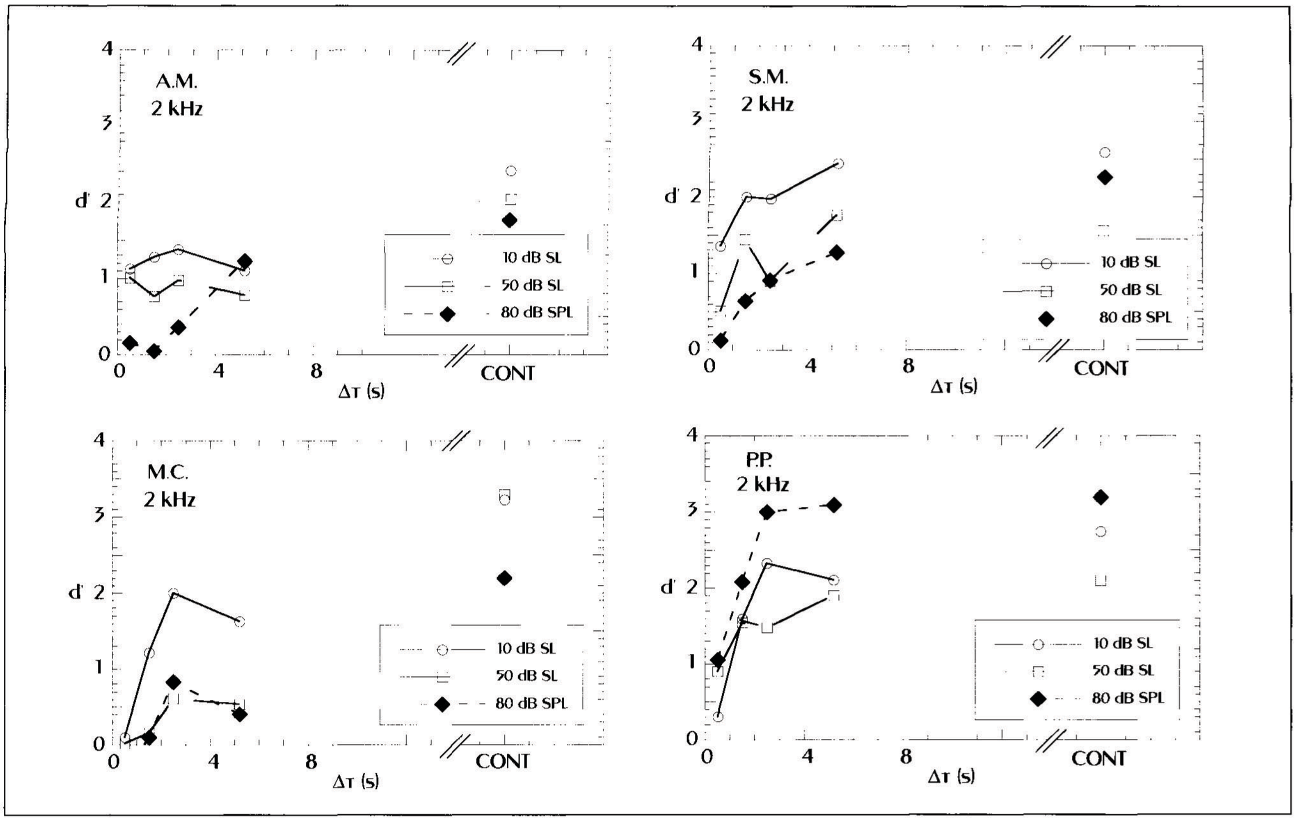

Figure 1. d' as a function of the delay between masker and signal onsets. The 50 ms signal and the masker are 2 kHz pure tones. Results for different masker levels and for each subject are reported.

experiments, but all subjects were tested at 0.5 and 4 kHz, for a 50 dB SL masker level, to obtain a common point of comparison for every subject. Not all results will be shown here.

3. Results

In the figures, d' is shown as a function of the delay Δt between the masker and signal onsets. The continuous condition is designated CONT.

3.1. Experiment 1: Masker frequency equals signal frequency

Figures 1, 2 and 3 show the individual results obtained for high frequencies (2, 4 and 8 kHz). For all subjects and all levels, d' was generally much higher for large values of Δt than for small values. Detection thus seems to be improved by increasing the delay Δt. We called this improvement "mid-term adaptation"; the choice of this term will be explained in the discussion. As shown in Figures 1 and 2, the more intense the masker, the more detection improved with delays in the signal. Indeed, d' generally increases from about 0 to about 2 from Δt=0 to the continuous condition at 2 kHz and 80 dB SPL; however, d' usually increases from about 1 to about 2 for lower levels. At 4 kHz and 80 dB SPL d' increases from 0 to more than 2.5 whereas it only increases from 0 to 2 (or 1 to 3) at 10 and 50 dB SL.

Figures 4 and 5 show the individual results obtained for low frequencies (500 Hz and 1 kHz). The improvement in detection depended on frequency. Figure 6 shows the mean of d' for each frequency and each masker level as a function of the delay between masker and signal onsets. For low frequencies (500 Hz and 1 kHz) an increase in delay did not produce a significant variation in d'. The significance of the results was verified by analysis of variance (ANOVA). On the other hand, for a more intense masker (80 dB SPL), a significant variation of d' was observed for these low frequencies and for all subjects ($p<0.06$ for a 500 Hz-masker, and $p<0.0001$ for a 1 kHz-masker).

In summary, for low masker levels, mid-term adaptation was observed only at high frequencies. But at 80 dB SPL, detection was improved for all frequencies when Δt was increased (Figure 6).

To determine the approximate range of signal level corresponding to the change in d' shown above, we measured signal threshold for a 500 ms-delay with a 4 kHz masker at 50 dB SL. The procedure used to measure the threshold was the same as that used for the continuous condition, except that the masker was pulsed and the delay between the masker and signal onsets was 500 ms. This threshold was 4 dB higher than the threshold for a continuous masker (mean of 5 subjects). This value is much smaller than the threshold differences commonly found for overshoot or temporal decline of masking (between 0 and 200 ms for example), but it is significant.

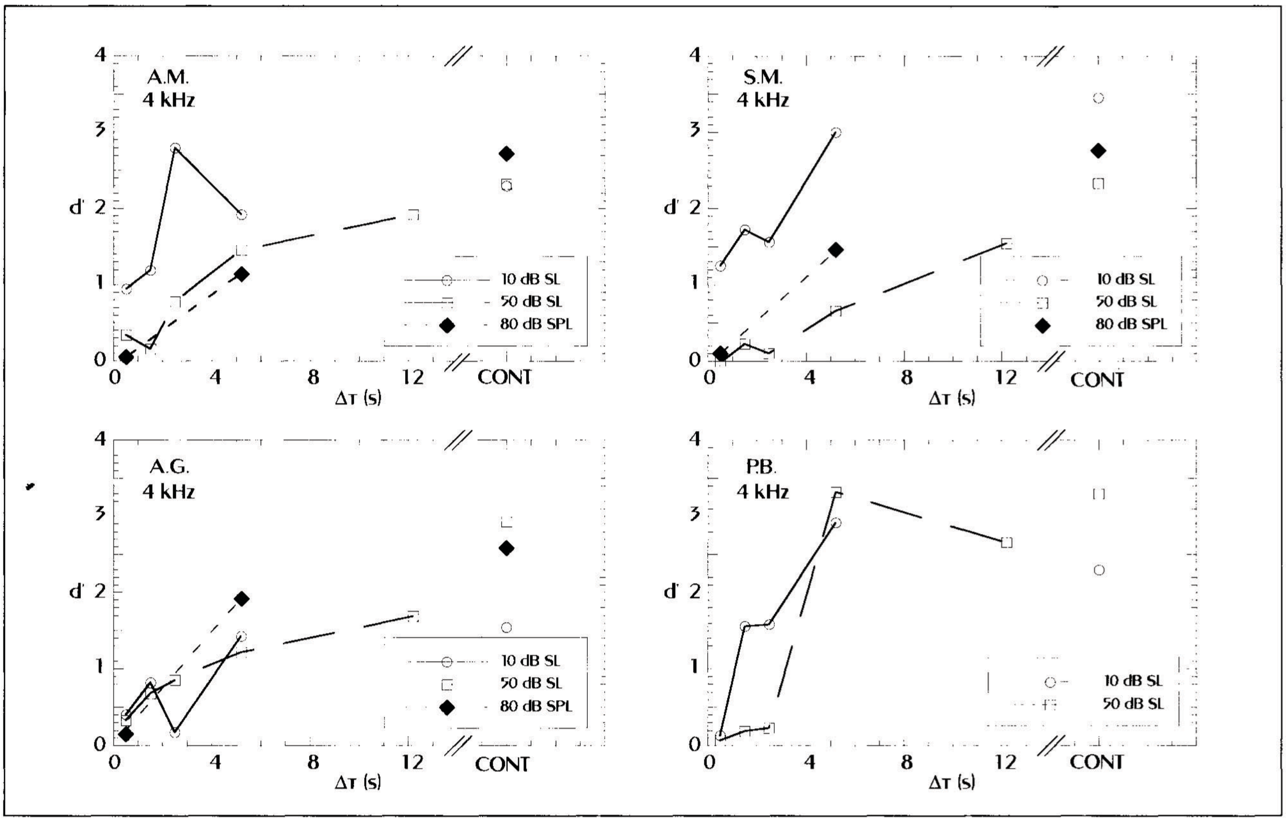

Figure 2. As in Figure 1 but for 4 kHz signals.

The exposure duration at which this mid-term adaptation reached an asymptotic value depended on masker level and frequency. The more intense or the higher the frequency of the masker was, the longer the duration. It is hard to determine the exact signal onset delay necessary to reach the asymptote, but it appears to be about 10 s. Our data show an asymptotic duration of about 5 s at 10 dB SL; Figures 1, 2, 3 (open circles) show that detection in the continuous condition was generally the same as in the pulsed condition for a delay of 5 s. This asymptotic duration was longer than 5 s for a 50 dB SL masker with frequency higher than 1 kHz (Figures 1, 2 and 3, open squares). Scharf *et al.* [19] estimated it at about 30 s for a 4 kHz pure-tone masker at 50 dB SL. At 80 dB SPL, the asymptotic duration of mid-term adaptation was about 5 s at 500 Hz, but for higher frequencies it was longer (Figures 1 to 5, filled diamonds).

Individual differences appear in these results (see Figures 1 to 5), as in previous studies on masked detection [6, 5, 8, 10, 11, 27]. However the data followed a general trend even though different frequencies and/or levels were needed to observe the same results among subjects.

Another interesting result was observed for low frequencies at the lower levels (500 Hz and 1 kHz at 10 and 50 dB SL). The variation of d' with Δt was not monotonic: it increased then decreased then increased again when Δt increased, especially at 500 Hz (Figure 6). The trend was similar at 1 kHz, except that d' decreased first then increased (Figure 6). We don't know how to explain this result which is shown for 3 out of 4 subjects (Figures 4 and 5).

3.2. Experiment 2: Masker frequency different from signal frequency

Three subjects were tested with a masker frequency different from the signal frequency. They had been tested in the previous experiment.

The experiments were first run at 50 dB SL, because a large effect was observed at that level when masker and signal had the same frequency (4 kHz). In this case, the detection for all subjects and all signal frequencies was not improved significantly when the delay was increased (not shown).

However, for a masker level of 80 dB SPL (Figure 7), there seemed to be an effect of masker fringe on signal detection for signal frequencies within the critical band for 2 subjects out of 3 (Figure 7b). For a signal frequency of 3.72 kHz, d' increased from about 0 to 2 (for A.M.) and 2.6 (for S.M.) when Δt varied from 500 ms to the continuous condition (Figure 7b). For the third subject no monotonic variation was observed: d' decreased then increased when Δt increased, and it was not so much larger in the continuous condition (d'=2.5) than for a Δt of 500 ms (d'=2.2). At lower signal frequency (2.8 kHz) the effect seemed to vanish for the two adapting subjects (A.M. and S.M., Figure 7a). For the third subject (S.P.), an effect of onset delay on signal detection was observed at 3.9 kHz (Figure 7c, d' varied from 1 to about 2.5 for Δt from 500 ms to the continuous condition).

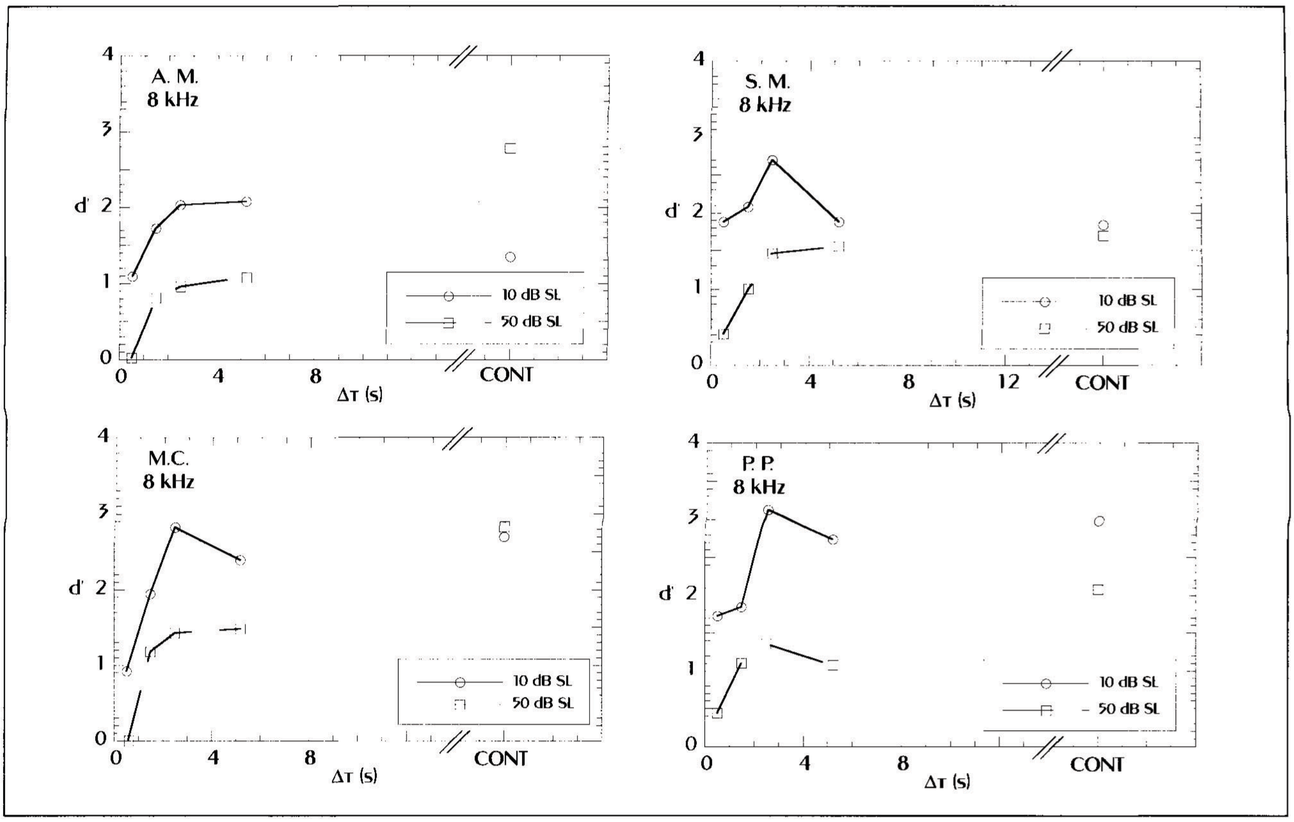

Figure 3. As in Figure 1 but for 8 kHz signals.

4. Discussion

4.1. Comparison of mid-term adaptation with temporal decline of masking and peripheral neural adaptation

It appears that the auditory system improves its ability to detect a change in a masking signal (intensity increment, added signal) as the duration of the masker fringe increases. Signal detection improved for fringes greater than 500 ms; that is for fringes longer than those used in temporal decline of masking experiments. Temporal decline of masking was observed for signals of less than 20 ms, but it seemed to occur also for longer signals [28, 14], that is for the same durations as we used. Temporal decline of masking is stronger for maskers and signals with different frequencies than for maskers and signals overlapping in frequency. This result is the reverse of what we found for longer fringe durations.

Different hypotheses have been offered to explain the decline of masking for short-duration fringes: spectral spread of masker, narrowing of the auditory filter, adaptation of suppression, transient masking, grouping, and peripheral neural adaptation to the masker (see [12] for a review).

Peripheral neural adaptation may explain the effect we found. It consists of a decrease of the discharge rate in auditory-nerve fibers stimulated by a constant stimulus. Most of the measurements showing this adaptation were done for stimulus durations of about 200 ms. But Lonsbury-Martin and Meikle [29] showed a decrease over a period of 24 s in the discharge of the auditory-nerve fibers of cats exposed one minute to a constant stimulus (85 or 90 dB SPL) at the characteristic frequency (CF) of the fiber. Ten Kate *et al.* [30] showed a decrease in firing rate with stimulus duration over 100 s in the dorsal cochlear nucleus of the cat. They also found that this decrease in firing rate as a function of duration increased with stimulus level. Viemeister *et al.* [31] showed the same effect on the auditory nerve of the cat, for high-frequency fibers at 20–40 dB above threshold. This adaptation was strong for fibers with a CF of more than 25 kHz; less adaptation was observed in fibers with lower CFs. Note that 25 kHz in the cat is comparable to 10 kHz in humans [32]. Javel [33] found a "long-term adaptation" and a "very long-term adaptation" in the auditory nerve of the cat. Long-term adaptation is the decrease in the discharge rate in the first several seconds after the stimulus onset, and very-long term adaptation is the decrease in the discharge rate over longer time exposure. But Javel [33] did not find any dependence of the amount of adaptation on CF.

Smith and Zwislocki [22, 23] showed that there is no neural adaptation on a short increment (20 ms), that is, during neural adaptation, the signal-to-masker ratio increases. This result was shown for delays up to 200 ms. If we assume that it is also true for longer delays and for longer increments (50 ms), our data are accounted for by neural adaptation. Indeed, if the signal to noise ratio increases during the exposure to the masker, the detection will improve.

We have used the word "adaptation" because it seems that the auditory system reduces its response to the masker in order to ignore it and to be more sensitive to another signal:

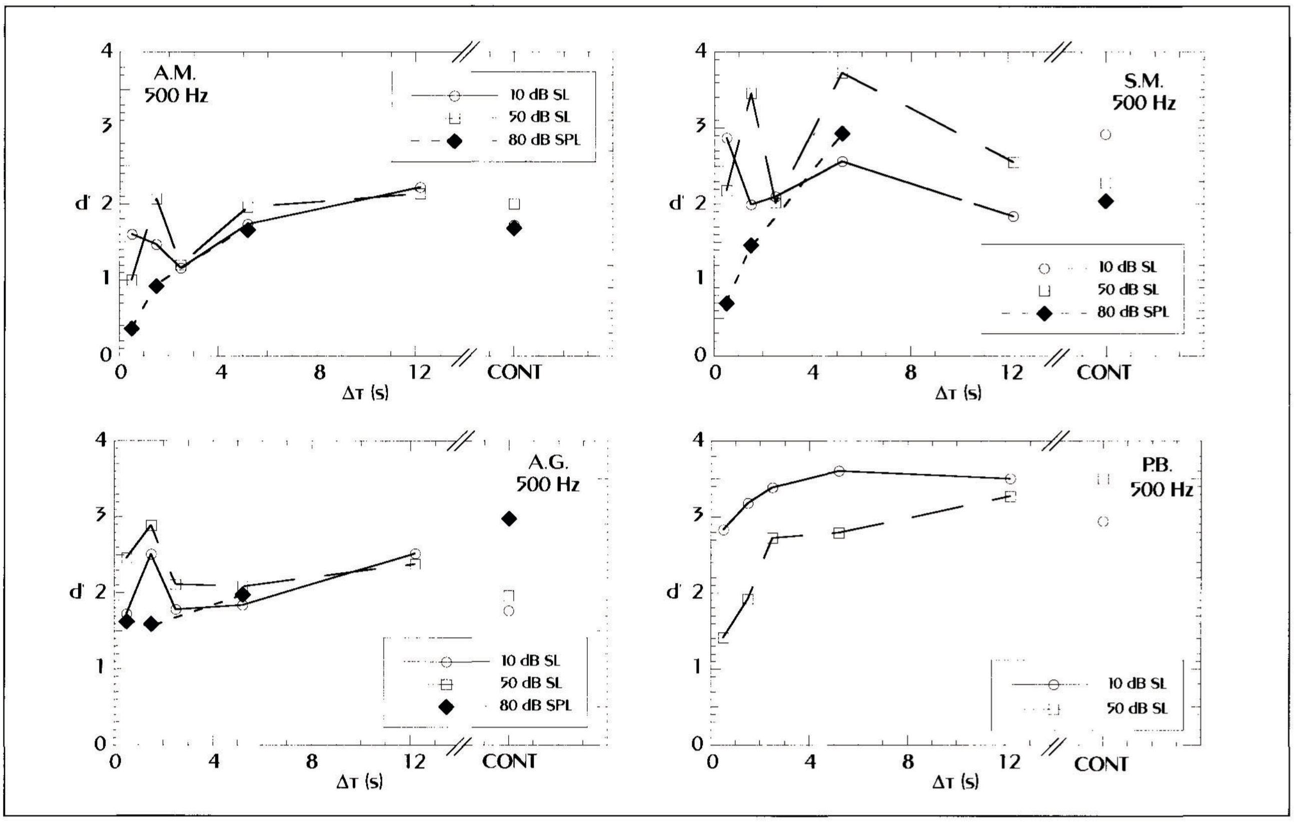

Figure 4. As in Figure 1 but for 500 Hz signals.

there is an "adaptation to masking". The asymptotic duration of this phenomenon was about 10 s. Therefore, we propose to call this effect "mid-term adaptation". Indeed, this duration is shorter than that for loudness adaptation (about 1 min, [34]) which could be called "long-term adaptation", and longer than short-term effects as in overshoot or in temporal decline of masking (about 100 ms).

The increase in neural adaptation with stimulus level is consistent with the increase in mid-term adaptation with masker level. The frequency dependence reported by Viemeister *et al.* [31] is consistent with our results. They found a duration of adaptation of about 10 s, which is close to ours (from 5 to 30 s, depending on masker level).

It is also fairly easy to explain the results for different masker and signal frequencies on the basis of peripheral neural adaptation. A sound with a given frequency excites mainly the auditory fibers tuned to this frequency, but other fibers with characteristic frequencies close to the sound frequency are stimulated too, albeit not so much. Therefore, some adaptation will occur in these fibers as well. If the stimulation is too weak, the adjacent fibers will not be excited enough to adapt. But if the level is high enough to produce a strong stimulation of these adjacent fibers, adaptation will appear on those fibers. Thus, the masker level needs to be high enough to induce adaptation at other frequencies.

Some authors have suggested that two mechanisms of masking were involved in temporal decline of masking: a within-channel process when masker and signal overlap in frequency and an across-channel process when masker and signal do not overlap. These two mechanisms may occur in two sites in the auditory system, which would produce different temporal decline of masking (see [14]). In mid-term effects as shown here, there may be a temporal decline of masking only on the within-channel process.

Viemeister *et al.* [31] found that the adaptation in cats was twice as strong for fibers with a low spontaneous firing rate than for fibers with a high rate of the same CF. On the other hand, fibers with a low spontaneous firing rate were presumed to be responsible for coding intensity of high-level signals [35, 36]. High-intensity signals should thus stimulate low spontaneous firing rate fibers which adapt more than high spontaneous firing rate fibers, and high-intensity signals would produce more adaptation than lower-intensity signals. This remark is consistent with what we found for humans. It is also consistent with the hypothesis suggesting that the coding of high-level signals is essentially done by low spontaneous discharge rate fibers.

4.2. Comparison of mid-term adaptation with the various forms of loudness adaptation

Another kind of adaptation has been found in the auditory system : loudness adaptation or perstimulatory fatigue. Loudness adaptation is a decrease in the loudness of a sound while its physical level is constant. This adaptation can be simple or induced by the addition of another short signal [37, 38, 39]. The inducer can be either in the same ear as the long signal (ipsilaterally-induced loudness adaptation) or in the other

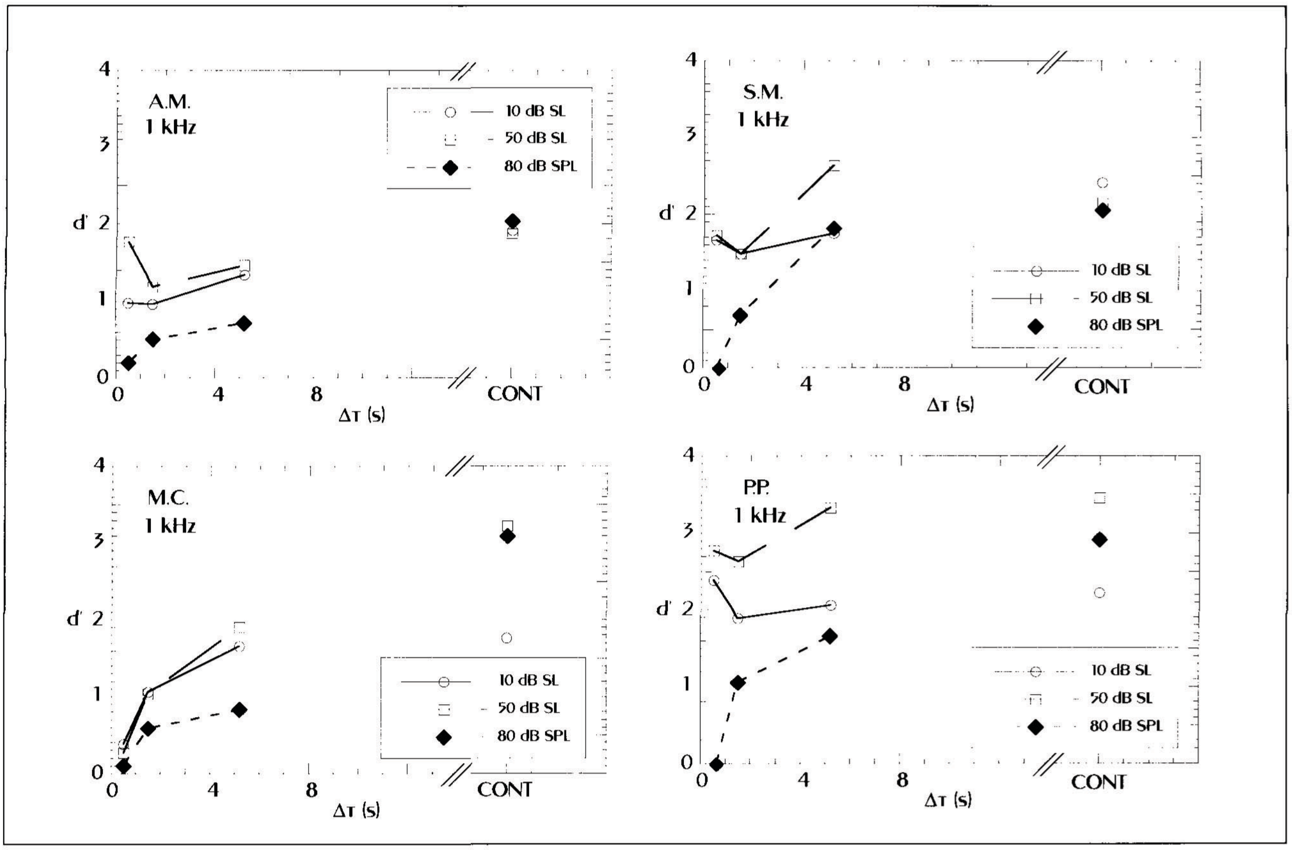

Figure 5. As in Figure 1 but for 1 kHz signals.

ear (contralaterally-induced loudness adaptation). One could hypothesize that loudness adaptation is responsible for the mid-term adaptation found here. But it does not seem to be true for either simple or induced loudness adaptation. Indeed, signal detection improved even without simple adaptation to the loudness of the masker (e.g. at 500 Hz and 80 dB SPL). It might be thought that, in our experiments, the added signal acted like an ipsilateral inducer. The level of the signal, however, was never more than 5 dB higher than that of the masker, and it has been shown [38] that ipsilaterally induced loudness adaptation occurs only for signals 5 dB higher than the masker. As a control, we measured the loudness of the masker over time with the same signal presentation as for increment detection (with the 50 ms signal added at some period to the masker). No correlation between mid-term adaptation and loudness adaptation (either simple or induced) was found.

Mid-term adaptation and ipsilaterally induced loudness adaptation seem to be different phenomena. Indeed, mid-term adaptation depends on the frequency of the masker, while ipsilaterally induced loudness adaptation does not depend on the test sound frequency [40]. Mid-term adaptation depends on the masker level whereas the parameter for ipsilaterally induced loudness adaptation is the difference in level between the inducer and the test signal [38].

One important point is that mid-term adaptation and simple loudness adaptation have the same variation with frequency: less adaptation was observed for low than for high frequency [34]. But they varied in an opposite way with level: loudness adaptation was observed for low levels [34], mid-term adaptation was greater for high masker levels. The mechanisms responsible for simple loudness adaptation remain mysterious. Different explanations have been proposed, but none seem suitable (see [34]). Schaaf [34] suggested that the auditory system adapts to long stimulation but that fluctuations can reduce or override the adaptation. These fluctuations may be in the stimulus or in the sensory organ. Thus, for a low-level stimulus, excitation remains fixed over a small group of fibers and no fluctuation will occur. For a high-level stimulus, excitation is widespread and unstable, and it leads to fluctuations precluding adaptation. How and where, in the auditory system, could temporal variation override adaptation? A common mechanism might be involved in loudness adaptation and mid-term adaptation: peripheral neural adaptation. For loudness, the adaptation would be reduced in most listening conditions because of fluctuations in the excitation. For detection, the auditory system would use only the signal-to-masker ratio to detect the signal in order to increase signal detectability after adaptation to the masker. This hypothesis could explain why variation with frequency was the same for loudness and mid-term adaptations (peripheral neural adaptation seems to be stronger for higher-frequency stimuli) and why it varied inversely for level (at high levels, fluctuation and spread of excitation could override loudness adaptation). But unfortunately, this explanation cannot account for the difference in asymptotic duration of loudness and mid-term adaptation.

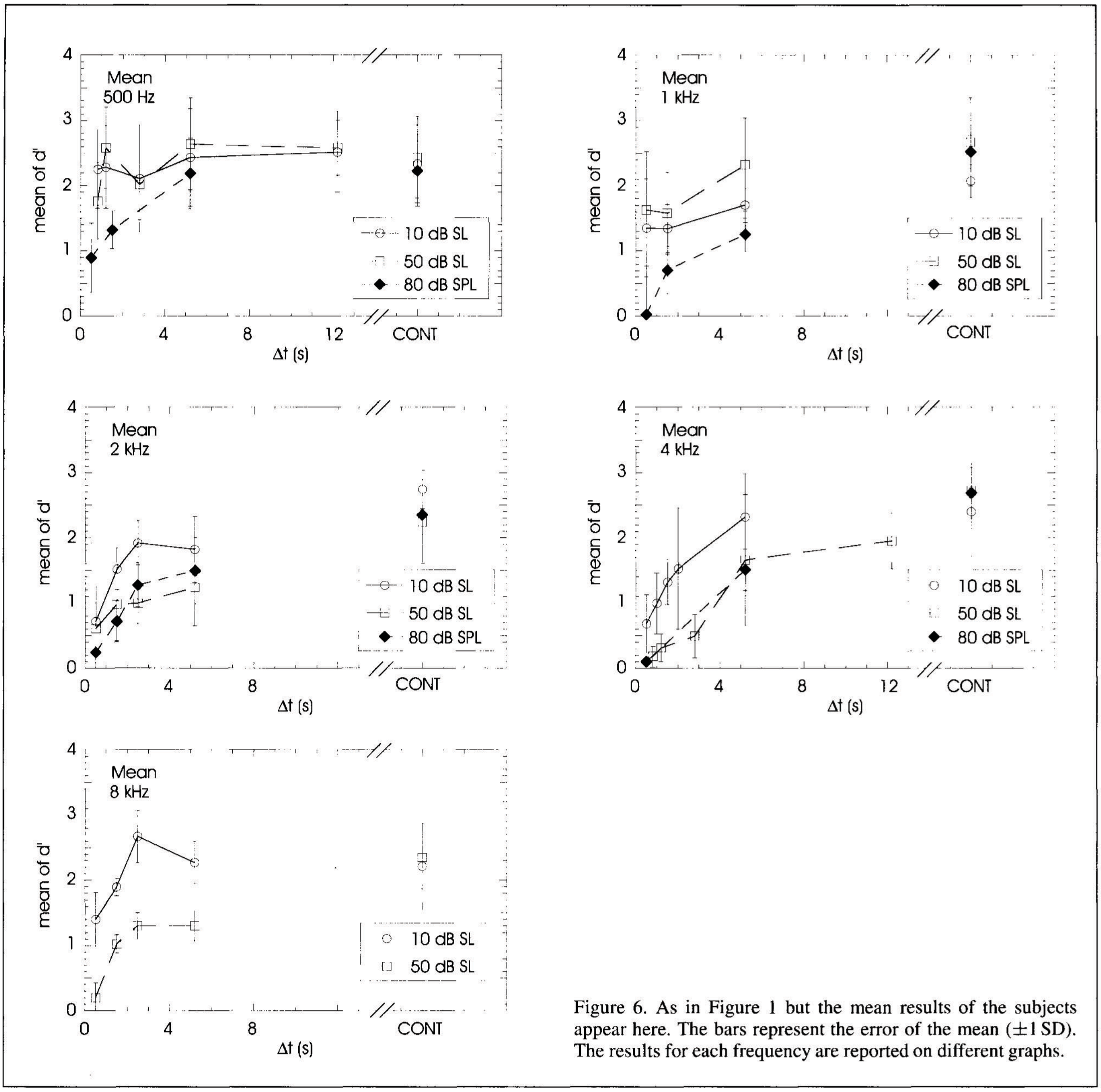

Figure 6. As in Figure 1 but the mean results of the subjects appear here. The bars represent the error of the mean (±1 SD). The results for each frequency are reported on different graphs.

5. Summary

It has long been known that detection of a signal embedded in a masker is strongly dependent on the masker duration preceding the signal. The experiments on this topic usually used maskers of 200 to 800 ms. Some years ago, it was shown that signal detection was still time dependent even for fairly long durations [18, 19]. Similarly, we found that prolonged exposure (10 s) to a masker improves detection for a signal. The improvement in detection can be seen as an adaptation effect, which we called "mid-term adaptation".

We showed that mid-term adaptation depends strongly on the level and frequency of the signals: the higher the frequency and the more intense the level of the masker, the greater the adaptation. Mid-term adaptation also depends on the relationship between masker and signal frequencies. The phenomenon seems to disappear quickly when signal frequency is different from masker frequency, and it seems that the masker needs to be intense (80 dB SL) to observe the phenomenon. Moreover, even at that level, signal frequency has to be close to the masker frequency to observe mid-term adaptation.

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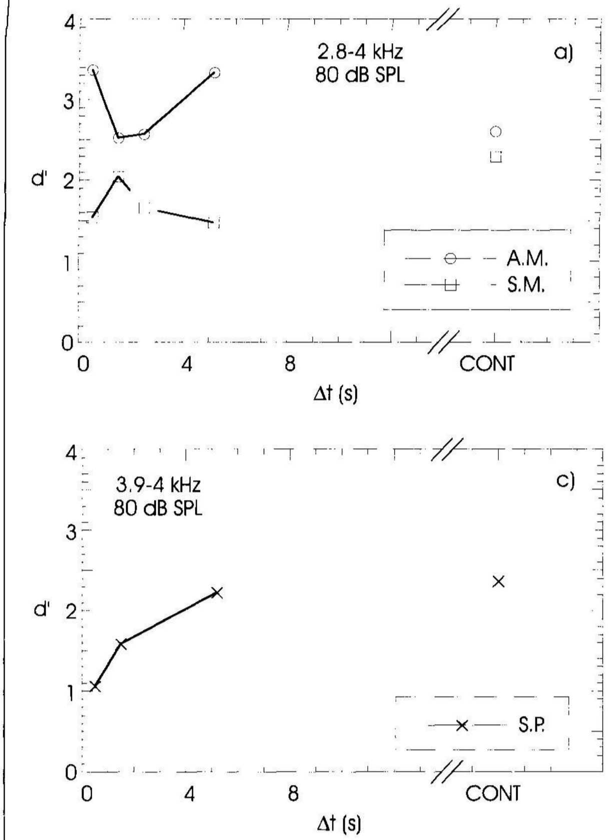

Figure 7. d' as a function of the delay between masker and signal onsets. The masker is a pure tone of 4 kHz and 80 dB SL. The 50-ms signal is a pure tone of: a) 2800 Hz b) 3720 Hz c) 3900 Hz.

References

[1] E. G. Wever, S. R. Truman: The course of the auditory threshold in the presence of a tonal background. J. Exper. Psychol. **11** (1928) 98–112.

[2] G. von Békésy: Zur Theorie des Hörens; über die Bestimmung des einem reinen Tonempfinden entsprechenden Erregungsgebietes der Basilarmembran vermittelst Ermüdungserscheinungen. Physik. Zeits. **30** (1929) 115–125.

[3] J. D. Harris: Studies of pitch discrimination in masking. II: The effect of signal/noise differential. J. Acoust. Soc. Am. **19** (1947) 816–819.

[4] J. P. Egan: Independence of the masking audiogram from the perstimulatory fatigue of an auditory stimulus. J. Acoust. Soc. Am. **27** (1955) 737–740.

[5] L. L. Elliott: Changes in the simultaneous masked threshold of brief tones. J. Acoust. Soc. Am. **38** (1965) 738–746.

[6] E. Zwicker: Temporal effects in simultaneous masking by white-noise bursts. J. Acoust. Soc. Am. **37** (1965) 653–663.

[7] E. Zwicker: Temporal effects in simultaneous masking and loudness. J. Acoust. Soc. Am. **38** (1965) 132–141.

[8] D. M. Green: Masking with continuous and pulsed sinusoids. J. Acoust. Soc. Am. **46** (1969) 939–946.

[9] H. Fastl: Temporal masking effects: III. Pure tone masker. Acustica **43** (1979) 282–294.

[10] S. P. Bacon, N. F. Viemeister: Simultaneous masking by gated and continuous sinusoïdal masker. J. Acoust. Soc. Am. **78** (1985) 1220–1230.

[11] S. P. Bacon, N. F. Viemeister: The temporal course of simultaneous tone-on-tone masking. J. Acoust. Soc. Am. **78** (1985) 1231–1235.

[12] B. A. Wright: Across-channel contributions to auditory enhancement. – In: Proc. of the 10th Intern. Symp. on Hearing. Manley et al. (eds.). World Scientific Publishers, Singapore, 1994, 470–479.

[13] N. F. Viemeister: Adaptation of masking. – In: Psychophysical Physiological and behavioral Studies in Hearing. G. van den Brink, F. A. Bilsen (eds.). Delft U.P., Delft, The Netherlands, 1980, 190–199.

[14] D. McFadden, B. A. Wright: Temporal decline of masking and comodulation masking release. J. Acoust. Soc. Am. **92** (1992) 144–156.

[15] E. Zwicker, H. Fastl: On the development of the critical band. J. Acoust. Soc. Am. **52** (1972) 699–702.

[16] B. Leshowitz, E. Cudahy: Masking patterns for continuous and gated sinusoids. J. Acoust. Soc. Am. **58** (1975) 235–242.

[17] D. McFadden: Spectral differences in the ability of temporal gaps to reset the mechanisms underlying overshoot. J. Acoust. Soc. Am. **85** (1989) 254–261.

[18] G. Canévet, B. Scharf, L. M. Ward: Détection d'un incrément d'intensité et adaptation de sonie. Acustica **74** (1991) 69–76.

[19] B. Scharf, G. Canévet, L. M. Ward: On the relation between intensity discrimination and adaptation. – In: Advances in the Biosciences. Pergamon Press plc., 83, 1992, 289–295.

[20] M. Florentine, S. Buus, C. R. Mason: Level discrimination as a function of level for tones from 0.25 to 16 kHz. J. Acoust. Soc. Am. **81** (1987) 1528–1541.

[21] N. Y.-S. Kiang: Discharge pattern of single fibers in the cat's auditory nerve. MIT res. monogr. 35. MIT Press, Cambrige, Mass., 1965.

[22] R. L. Smith, J. J. Zwislocki: Responses of some neurons of the cochlear nucleus to tone-intensity increments. J. Acoust. Soc. Am. **50** (1971) 1520–1525.

[23] R. L. Smith, J. J. Zwislocki: Short-term adaptation and incre-

mental responses in single auditory-nerve fibers. Biol. Cybern. **17** (1975) 169–182.
[24] R. L. Smith: Short-term adaptation in single auditory nerve fibers: Some poststimulatory effects. J. Neurophysiol. **40** (1977) 1098–1112.
[25] R. L. Smith: Adaptation, saturation and physiological masking in single auditory-nerve fibers. J. Acoust. Soc. Am. **65** (1979) 166–178.
[26] H. Levitt: Transformed up-down methods in psychoacoustics. J. Acoust. Soc. Am. **49** (1971) 467–477.
[27] D. McFadden: Absence of overshoot in a dichotic masking condition. J. Acoust. Soc. Am. **83** (1988) 1685–1687.
[28] D. McFadden, B. A. Wright: Temporal decline of masking and comodulation detection differences. J. Acoust. Soc. Am. **88** (1990) 711–724.
[29] B. L. Lonsbury-Martin, M. B. Meikle: Neural correlates of auditory fatigue: frequency-dependent changes in activity of single cochlear nerve fibers. J. Neurophysiol. **41** (1978) 987–995.
[30] J. H. Ten Kate, J. Raatgever, F. A. Bilsen: Neural responses to cosine noise in a wide range of intensity levels. 9ème congrès international d'acoustique, Madrid, 1977. 4/9–VII J4 P512.
[31] N. F. Viemeister, E. Javel, S. P. Bacon: Psychophysical and physiological correlates of high-frequency tone decay. Abstract from the 8th Midwinter Meeting of the Assoc. for Res. in Otolaryngol., 1985.
[32] D. D. Greenwood: A cochlear frequency-position function for several species-29 years later. J. Acoust. Soc. Am. **87** (1990) 2592–2605.
[33] E. Javel: Long-term adaptation in cat auditory-nerve fiber responses. J. Acoust. Soc. Am. **99** (1996) 1040–1052.
[34] B. Scharf: Loudness adaptation. – In: Hearing research and theory, Vol.2. J. V. Tobias, E. D. Schubert (eds.). Academic Press, New York, 1983, 1–56.
[35] N. F. Viemeister: Psychophysical aspects of auditory intensity coding. – In: The Auditory System: Development Physiology and Psychophysics. G. M. Edelman, W. E. Gall, W. M. Cowan (eds.). Wiley, New York, 1988, 213–241.
[36] N. F. Viemeister: Intensity coding and the dynamic range problem. Hear. Res. **34** (1988) 267–274.
[37] M.-C. Botte, G. Canévet, B. Scharf: Loudness adaptation induced by an intermittent tone. J. Acoust. Soc. Amer. **72** (1982) 727–739.
[38] G. Canévet, B. Scharf, M.-C. Botte: Loudness adaptation, when induced, is real. Brit. J. Audiol. **17** (1983) 49–57.
[39] C. Baruch: Etude d'une interaction binaurale: l'adaptation induite de la sonie. Thèse de doctorat de psychologie expérimentale, Université Paris V, 1987.
[40] S. Charron, M.-C. Botte: Frequency selectivity in loudness adaptation and auditory fatigue. J. Acoust. Soc. Am. **83** (1988) 178–187.